Soil Erosion from Two Small Construction Sites, Dane County, Wisconsin

Introduction

Soil erosion from construction sites has long been identified as a significant source of sediment and other suspended solids in runoff in many parts of the United States (Hagman and others, 1980; Yorke and Herb, 1976; Becker and others, 1974). In some states, such as Wisconsin, sediment has been identified as the number one pollutant (by volume) of surface waters (Wisconsin Department of Natural Resources, 1994). Because numerous water-quality problems in streams are associated with excessive sedimentation, Federal and state regulations requiring erosion-control measures at construction sites larger than 5 acres have been developed and implemented from the 1970's to the present. During the 1990's, excessive erosion and sediment production associated with small residential and commercial sites of less than 5 acres has been increasingly recognized for its effects on streams—not only erosion from individual sites but also erosion from discontinuous groups of sites within a stream basin.

Currently, most Federal, state, and local construction regulations require some type of erosion control plan for sites disturbing more than 5 acres. On sites less than 5 acres, minimal erosion control measures are required. In most instances, only perimeter controls (silt fences and straw bails) and tracking pads (crushed stone or gravel at vehicle access points) are required as erosion control practices. In the U.S. Environmental Protection Agency Phase II Stormwater Rules, erosion control will be required on sites less than 5 acres (small construction sites) beginning in 2003. The purpose of the project was to evaluate the significance of erosion on construction sites less than 5 acres as a source of sediment to surface waters.

Overview

Numerous studies have shown that the amount of sediment transported by stormwater runoff from large construction sites (greater than 5 acres) with no erosion control practices in place is significantly greater than from sites with erosion controls (U.S. Environmental Protection Agency, 1999). This Fact Sheet evaluates water-quality data collected by the U.S. Geological Survey (USGS) and the Dane County Land Conservation Department from June 1998 to July 1999 from two small construction sites (less than 5 acres)—one residential and one commercial—in Dane County, Wisconsin (fig. 1). Study data characterizing the magnitude of erosion from these two typical small construction sites will be used in the formulation of U.S. Environmental Protection Agency's National Pollution Discharge Elimination System (NPDES), regulations requiring erosion control practices on construction sites that disturb less than 5 acres.

Results of this USGS/Dane County Land Conservation study indicated that small construction sites are potential sources of large amounts of sediment erosion. Sediment loads from the two monitored construction sites were 10 times larger than typical loads from rural and urban land uses in Wisconsin. Total and suspended solids concentrations data indicate the active construction phase produced concentrations that were orders of magnitude higher than pre- and post-construction periods. Furthermore, these concentrations were dramatically reduced when the site was seeded and mulched. These results support the need to design and implement erosion control plans.

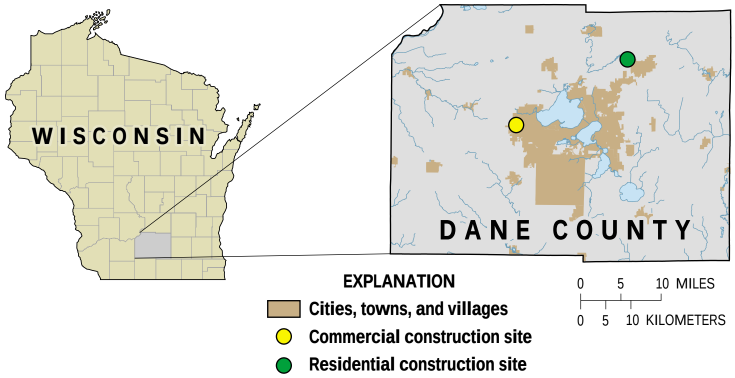

Figure 1. Location of study sites in Dane County.

Why study small construction sites?

Water-quality impacts

When left uncontrolled, large amounts of soil and other small particles—collectively called sediment—can move off of construction sites along with other attached pollutants. By volume, sediment is the greatest pollutant entering our surface waters, and causes multiple problems. Sediment buries plant and animal habitat critical to healthy streams, lakes, and wetlands. Loss of habitat reduces the number, diversity, and productivity of plants and animals living in aquatic environments. Sediment that remains suspended in the water column reduces water clarity, inhibits aquatic plant growth, lowers the esthetic and recreational values of water resources, and makes it difficult for some fish to find food. Suspended sediment increases the solar heating of water, scours aquatic life in streams, and clogs the gills of fish and aquatic insects. Warm water holds less oxygen than cooler water (oxygen is vital to aquatic animals) and increased water temperatures are stressful to coldwater fish such as trout. Particulate-bound nutrients, such as phosphorus delivered to surface waters by eroded soils, often causes algal blooms and alterations in the food chains, which further reduces the quality of these water resources.

Number of construction sites in Dane County, Wisconsin

Hundreds of small and potentially problematic construction sites are being built upon in Dane County, Wisconsin, as urban and suburban development rapidly expands into the surrounding rural areas. For example, residential building permits issued in Dane County increased 15 percent in a single year, from 1,489 in 1997 to 1,709 in 1998 (Rosenberg, 1999). As urban sprawl continues in Dane County and in many other rapidly developing areas of the United States, erosion control at small construction sites will become an increasingly important issue as the water quality of streams, rivers, and lakes becomes degraded by sediment.

Cumulative effect of small construction sites

The cumulative effect of construction activities on a small site can be significant when compared to the platting (installation of roads, sewers, and utilities) of the subdivision. Several reasons exist:

- Paved roads, curbs and gutters, and storm sewers effectively convey runoff water and associated sediment away from the sites.
- More equipment and vehicles are taken on and off the small construction sites per unit area than for platting; this causes mud and debris to be tracked from the site and also causes increased soil compaction, which reduces infiltration

and increases runoff volume. The tracked mud and debris is deposited on the roads, which are usually connected to the stormwater drainage system.

- Erosion rates caused by construction activities have the potential to be higher than erosion rates from platting because of the steep, uncovered high-slope soil piles that are created when topsoil is stripped and when basements or foundations are excavated.

How and when were the Dane County sites studied?

Site selection

Two small construction sites in Dane County, one residential and one commercial, were selected to represent typical construction activity on sites less than 5 acres in size (fig. 1). The residential lot was 0.34 acres with an average slope of 8 percent, and the commercial office development lot was approximately 1.72 acres with an average slope of 4 percent.

Sites were selected on the basis of five criteria:

1. The site had to be stabilized or without construction activity for a sufficient period to allow for pre-construction monitoring of water quantity and water quality.
2. The site had to accommodate small wing walls or other structures that would direct discharge from a significant area of the site to a single discharge point.
3. The site had to be smaller than 5 acres.
4. Construction on the site had to be completed by September 1998.*
5. The builder had to agree to the proposed monitoring plan.

*Note: Some changes in scheduling occurred after site selections were made.

Site monitoring

Because the objective of the study was to quantify the movement of soil during construction activity, erosion control practices were not evaluated as part of this study. At both the commercial site and the residential site, erosion controls were placed downstream from the monitoring equipment. The monitoring equipment installed at each site is shown and described in figure 2.

Data were recorded hourly during dry periods. Rainfall and flume water levels were recorded every minute during periods of rainfall and runoff. Collection of individual water-quality samples was triggered by the datalogger during runoff by using time pacing (for example, 5 minutes between samples). This time pacing could be adjusted to ensure that the samples were representative of the entire storm, particularly the period of increasing runoff in the beginning.

Samples were split and processed for analysis. Processed samples were taken to the Wisconsin State Laboratory of Hygiene for determination of the concentrations of total and suspended solids (the measures used to represent sediment).

Load computation

Solids loads were computed by multiplying runoff volume, solids concentration, and a constant for unit conversion. The loads, rainfall, and runoff

Monitoring equipment includes:

- **A.** Tipping-bucket raingage to measure rainfall depth and intensity;
- **B.** Datalogger to record data from the sensors, trigger the collection of samples, and alert USGS personnel about rainfall and runoff;
- **C.** Modem to retrieve data and to monitor sites during rainfall and runoff;
- **D.** Automatic water-quality sampler to collect samples during storms;
- **E.** Pressure transducer and flume to measure water level and estimate runoff volume; and
- **F.** Plywood wingwalls to funnel runoff from the site to a single discharge point.

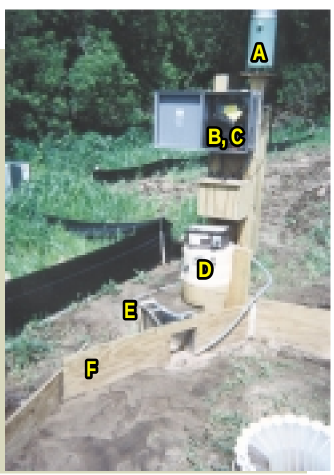

Figure 2. Monitoring equipment installed at construction sites.

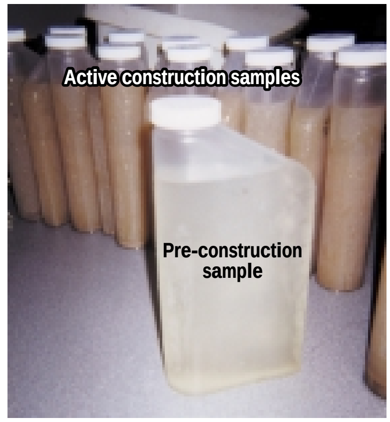

Photo 1. *Water-quality samples from the commercial construction site.*

Photo 2. *Residential construction site after monitoring equipment was installed in June 1998.*

Table 1. Summary table for the sampled runoff events for (A) the commercial construction site, and (B) the residential construction site [Precip., precipitation; lbs, pounds; mg/L, milligrams per liter]

A Commercial construction site

Sampled runoff event			Storm information		Average solids loads		Event mean concentration (EMC)	
Number	Start date	Construction phase	Precip. depth (inches)	Runoff volume (cubic feet)	Total solids (lbs)	Suspended solids (lbs)	Total solids (mg/L)	Suspended solids (mg/L)
B-1	6/27/98	Pre	1.92	32	0.3	0.2	138	94
B-2	7/3/98	Active	0.72	669	901	931	21,580	22,285
B-3	7/6/98	Active	0.26	26	25	26	15,605	16,216
B-4	7/7/98	Active	0.32	526	528	581	16,086	17,700
B-5	7/19/98	Active	0.80	236	325	327	22,032	22,176
B-6	7/20/98	Active	0.61	219	342	272	25,065	19,939
B-8	8/4/98	Active	0.50	803	136	129	2,721	2,574
B-10	8/23/98	Active	0.96	1,601	1579	1479	15,803	14,803
B-12	10/5/98	Active	0.45	756	100	91	2,117	1,925
B-13	10/17/98	Transition	0.80	1,940	399	389	3,296	3,211
B-14	11/9/98	Transition	0.72	1,351	107	96	1,263	1,134
B-15	4/21/99	Transition	0.46	952	87	81	1,462	1,364
B-16	5/16/99	Transition	1.49	2,059	318	288	2,475	2,237
B-17	5/23/99	Post	0.42	788	18.1	12.5	368	255
B-18A,B	6/1/99	Post	0.67	1,112	7.9	5.3	114	76
B-19	6/4/99	Post	0.27	455	3.5	2.4	124	86
B-20	6/6/99	Post	1.01	1,983	24	20	193	159

B Residential construction site

Sampled runoff event			Storm information		Average solids loads		Event mean concentration (EMC)	
Number	Start date	Construction phase	Precip. depth (inches)	Runoff volume (cubic feet)	Total solids (lbs)	Suspended solids (lbs)	Total solids (mg/L)	Suspended solids (mg/L)
SH-1	6/27/98	Pre	0.81	359	314	315	14,029	14,074
SH-2	7/20/98	Pre	1.07	129	11.3	10.5	1,408	1,298
SH-4	8/4/98	Pre	0.69	78	4.07	3.60	837	740
SH-5	8/4/98	Pre	0.48	167	5.45	4.31	523	414
SH-6	8/24/98	Pre	0.70	394	26.5	24.2	1,079	986
SH-7	9/14/98	Pre	2.10	99	0.924	0.519	149	84
SH-8	10/5/98	Pre	0.98	142	2.97	2.20	336	249
SH-9	10/17/98	Pre	0.99	39	0.407	0.172	168	71
SH-10	11/9/98	Active	1.72	309	57.8	49.9	2,999	2,587
SH-11	4/8/99	Active	1.95	178	39.7	34.2	3,576	3,074
SH-12	4/21/99	Active	1.07	69	7.70	6.47	1,789	1,503
SH-13	7/17/99	Post	1.60	113	0.602	0.135	85	19
SH-14	7/19/99	Post	0.40	70	0.655	0.303	150	69
SH-15	7/20/99	Post	0.53	57	0.568	0.202	161	57

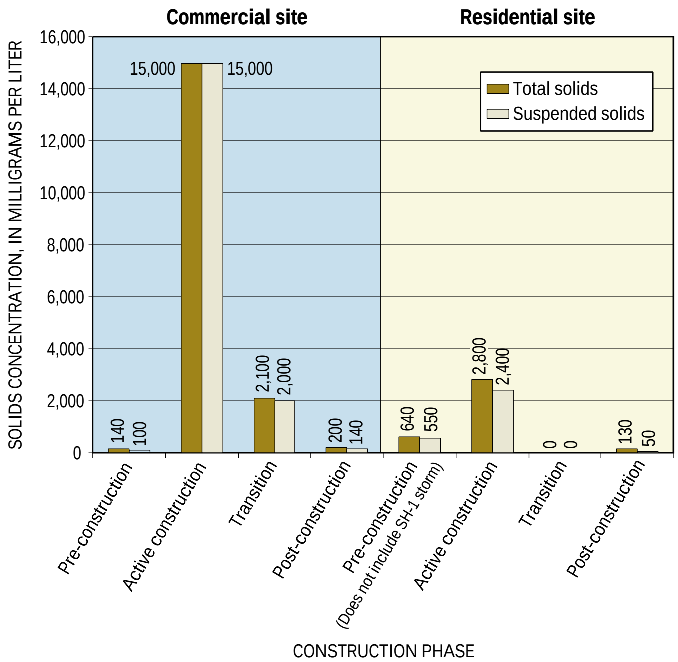

Figure 3. Average event mean concentrations for total and suspended solids for the commercial and residential construction sites.

summaries are presented in tables 1A and 1B. Event-mean concentrations (EMC's) were computed by dividing the average load by the runoff volume and a unit conversion factor. Regression models were developed for the EMC's for each phase of construction (pre-construction, active construction, transition and post-construction) for each construction site using 5-minute maximum intensity and total precipitation depth. This regression model was used to estimate loads for the nonsampled storms so that an annual load could be computed. Total solids analysis quantifies the suspended and dissolved solids in a sample. In general, values for total solids should be greater than those for suspended solids, but analysis errors can cause values for suspended solids to be greater than those for total solids.

Construction and monitoring timelines

Commercial site

Pre-construction-phase monitoring began on June 20, 1998. A storm on June 27, 1998 was the only pre-construction storm that produced runoff. Despite a 1.92-inch rainfall, only 0.2 pounds of suspended solids were measured in runoff (table 1A and photo 1). This was the largest storm during the study, yet it represented the smallest amount of suspended solids discharged in runoff.

Active construction began the first week of July 1998 and continued through the storm on October 17, 1998. This timing was critical because it occurred during the summer months when the highest rainfall intensities occurred.

Landscaping and site stabilization (transition phase) began in November 1998 and was completed in May 1999. Suspended-solids loads measured in storm runoff decreased substantially during this phase, coincident with stabilization of soil at the site.

Residential site

Pre-construction-phase monitoring began on the residential site in June 1998. Initial sediment concentrations and loads from the first monitored storm (June 27, 1998), (SH-1, table 1B) were significantly higher than the events sampled later. This was because the site had very little vegetative cover, making it susceptible to erosion (photo 2). The site was seeded with annual rye grass to help prevent erosion. Suspended solids loads in runoff during subsequent storms dropped dramatically after the grass cover was established. This reinforced the importance of proper seeding and mulching to reduce runoff.

Active construction began in November 1998 and was completed in May 1999. Three storms were monitored during the active construction phase. Because most of the construction took place during the winter months when the ground was frozen, few storms produced runoff. Those storms, however, did show that residential development could be a significant source of suspended solids.

Post-construction monitoring resumed after the site was considered stable. Three events were monitored during July 1999; all sampling results indicated very low suspended-solids loads.

What were the results?

Construction phase producing the most sediment

A summary of the data collected during runoff events at the two sites (tables 1A and 1B and fig. 3 show that during active construction, the average EMC of solids increased dramatically when compared to pre-construction and post-construction EMC's. This finding indicates that the active construction phase is the most important phase to control.

Factors affecting sediment production

Several factors contributed to increased erosion during active construction. First, the vegetative cover is removed from the site. Vegetative cover reduces raindrop energy, and plant roots hold the soil in place. When vegetation is removed, the protective cover is removed. Seeding and site stabilization substantially reduce the concentration of solids in the runoff. A dramatic reduction in EMC for both sites after stabilization is depicted in figure 3. Second, heavy equipment compacts the soil, resulting in increased runoff volume. This is demonstrated by sampled events B-1 and B-2 (table 1A). A 1.92-inch, high-intensity rainfall on June 27, 1998, produced a runoff volume of 32 cubic feet, whereas a 0.72-inch rainfall on July 3, 1998 just after the soil was stripped produced 670 cubic feet of runoff.

Differences between event mean concentrations of solids

The primary reason for between-site differences in EMC's was the time of active construction. Construction at the commercial site was completed during the summer, when short, but high-intensity rainfalls are common; in contrast, the residential active construction was completed during the winter, when rain tends to fall at low intensity in protracted periods. Evidence indicates that the EMC's at the residential site would be as high as those of the commercial site if the active construction period occurred during the summer months. The first sampled storm at the residential site was monitored when the site was similar to an active construction site. Much of the ground had little or no cover (photo 2). The EMC for that storm (SH-1) was 14,000 mg/L, which was similar to that for several storms monitored at the commercial site.

Application of Universal Soil Loss Equation

The Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978) predicted a soil loss of 8.8 tons for the commercial site and 1.7 tons for the residential site over the construction period. As is evident from figure 4, agreement between predicted soil loss and actual sediment load is closer for the commercial site.

Several factors explain the difference between the sum of the monitored and estimated loads and the predicted loads at the residential site. The first is that

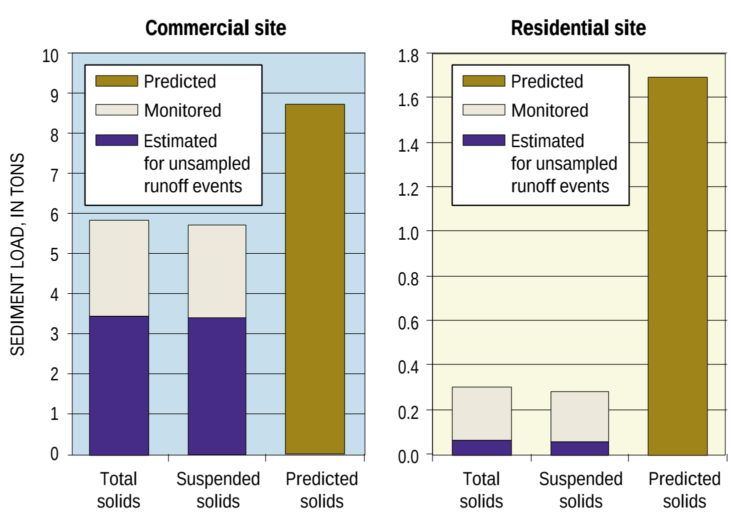

Figure 4. Predicted (by USLE), monitored, and estimated total and suspended solids loads for the commercial and residential construction sites.

active construction took place during the winter months, when the monitoring equipment was deactivated. A second reason is that the USLE predicts soil erosion, not sediment yield. Soil erosion is the process of soil particles being detached from the soil surface. Sediment yield, on the other hand, is the process of detached soil being transported from a specific area. Not all soil that is eroded will leave the site; therefore, the sediment yield should be lower than the amount of soil that is eroded. The monitoring results indicate the amount of soil that is leaving the construction site, which is sediment yield.

Comparison of unit-area loads

Comparisons of sediment yield from various land uses can be made if the yields are expressed as unit-area loads, which are defined as the mass of a particular constituent transported by a stream, divided by the drainage area of the watershed (Corsi and others,1997). For this study, the loads from the two construction sites were converted to pounds per acre. Data from the construction sites were based on one year of monitoring and represent the total load estimated for that given year. The unit-area loads for other land-use categories (fig. 5) reflect the median load from multiple years of data. The relative significance of construction is evident in figure 5.

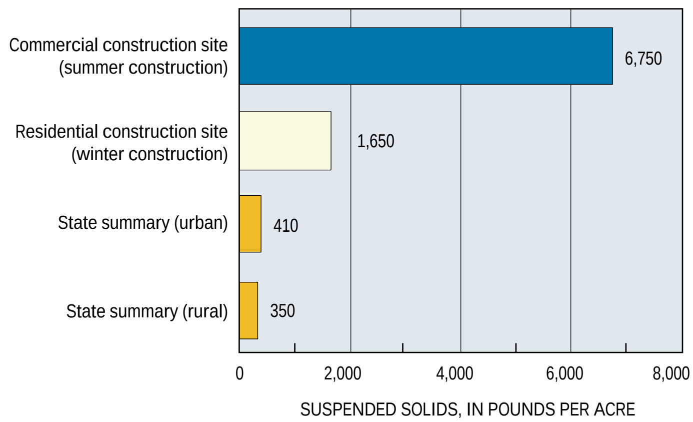

Figure 5. Unit-area solids loads for residential and commercial construction sites, compared with state summaries for urban and rural land uses.

Rainfall during study period

The rainfall during the monitoring period was close to the 30-year long-term average for Madison, Wis. (fig. 6). The exception was April 1999, when the rainfall was nearly double the long-term average for that month.

First flush phenomenon

The data do not show a direct correlation between sediment yield and the first rainfall (first flush) during the active construction phase. Discrete concentrations of total and suspended solids were related more to rainfall intensity than the first flush.

Application of results to other areas

The project results show the magnitude of the erosion problem for small construction sites. Soil type, site slope, type of erosion control practices installed, rainfall depth and intensity, and other factors play a large role in erosion and transport of sediment off the site. This project serves as an indicator that small construction sites are a significant contributor of sediment loading to surface waters if proper erosion controls are not implemented.

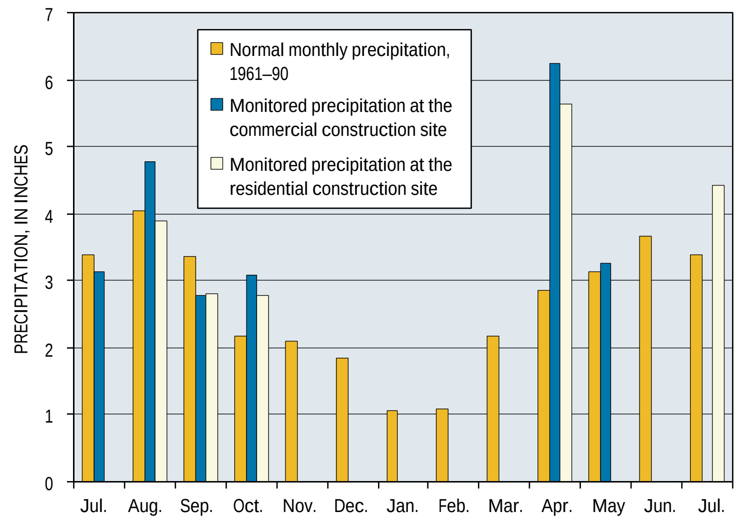

Figure 6. Normal (30-year) monthly precipitation and monitored precipitation at the commercial and residential construction sites.

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Acknowledgments

We would like to thank the Dane County Lakes and Watersheds Commission for providing printing costs. We would also like to thank the Blettner Group and homeowners Ron and Karen Blawusch for cooperating and providing access to their property.

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